Performance Metrics for Power Converter Stewardship

A Key Element of an Effective Maintenance Strategy

Craig Burkhart
RF Accelerator Research & Engineering Division
September 25, 2014

U.S. DEPARTMENT OF ENERGY
Office of Science
SLAC NATIONAL ACCELERATOR LABORATORY

Value of Performance Metrics to POCPA Stewardship

"Why does power conversion support cost so much?"

- What service are you providing, "fire department"?
- To provide efficient service, we must be proactive, not reactive
- Effective performance metrics provide quantitative justification for proactive elements of stewardship efforts
- Tool to manage customer expectations

As Engineers/Scientists we are "data driven"

- "How can you manage what you don't measure?"
- Effective performance metrics provide time-resolved measure of effectiveness of elements of stewardship program

General Characteristics of Effective Performance Metrics, aka Key Performance Indicators (KPIs)

Based on data, which should be relatively simple to obtain

- Look to standardized data sets; OCFO financial reports, Accelerator Operations machine availability reports, …
- This data is important to the Laboratory, not just power conversion

Measure a controllable characteristic of your stewardship effort

Have a standard or reference value

- May be relative; system repair in FY14 cost $0.43M
- Or absolute; system availability in FY14 was 99.37%

Are SMART (Specific, Measurable, Achievable, Relevant to the organization, and Time-based)

“Obvious” Stewardship Metrics

System availability

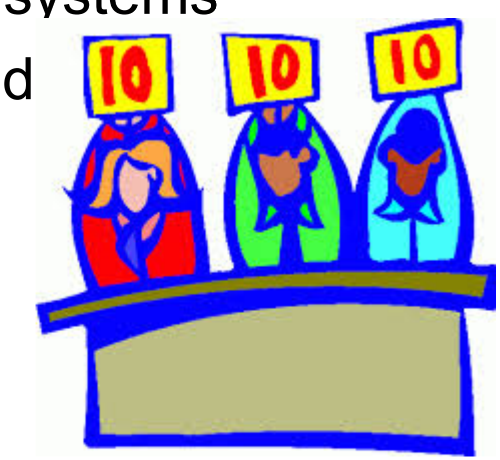
- Requires consistent and reasonable assignment of down time

Stewardship costs

- Lab business models are not designed to provide an absolute assessment

System performance

- Difficult to define a single SMART metric that accurately indicates performance, even for simple systems
- Typically an array of metrics is employed
- What is important to your customer?



Availability Metric

Availability is a key metric for User Facilities

- "Operations" usually assigns goals and tracks system availability
- System definitions must be meaningful to stewardship

"Math of availability" provides stewardship focus

- A = MTTF/MTBR
- MTTF = MTBR – MTTR
- MTTF: mean time to failure
- MTBF: mean time between failures
- MTTR: mean time to repair

Limitations of availability metric

- Poor maintenance practices only identified after the fact
- "Excessive" availability → excessive maintenance costs (DOE comment, "reducing availability from 95% to 85% reduces maintenance costs by 30%")
- "Good" availability metric is necessary, but not logically sufficient, to demonstrate effective stewardship

Cost Metric: Reference Value?
(Trend Up or Trend Down, but is it Good?)

Hourly rate – dominated by Lab cost model

- Management
- Infrastructure
- Regional wage factors

Total system stewardship costs – dominated by unique machine attributes

- Linac versus synchrotron
- NSLS-I versus NSLS-II

Can be applied locally with fidelity

Reference value can be established in collaboration with customer

Alternate Cost Metric: Return On Investment (ROI)

Concept

- The cost of system improvement (investment) is offset/ reduced by a resultant reduction in recurring stewardship costs (return)

Advantages

- Investment and return share same cost reference value

Limitations

- Only applicable to “improvements” (includes preventative maintenance)

Mission Readiness: ROI-Based Infrastructure Upgrade

Challenge

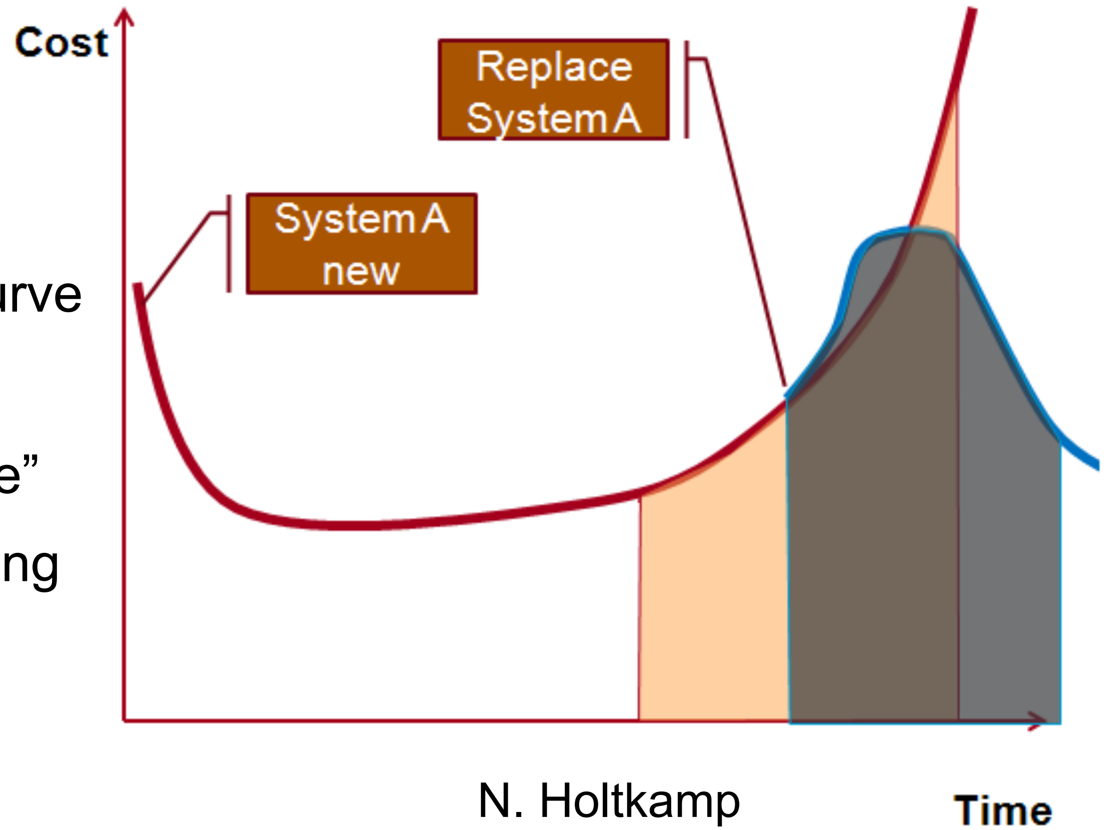
- Much of SLAC’s core mission employs half-century old accelerator infrastructure
- Significant portions of that infrastructure must be replaced (it will fail or fail to meet evolving requirements) to achieve long-term mission objectives
- What is the most cost-effective strategy to guide infrastructure investment?

Mission Readiness (MR) for LCLS based on a 2-element ROI strategy

- Repair and maintenance costs (ROI-M)
- Risk-based program impact (down time) costs (ROI-D)

Mission Readiness: The Business Model

- System reliability and maintenance costs follow a "bathtub curve"
- Investment can "reset" the curve
- Time-integrated costs over "investment and a reset curve" are lower than continuing along "original curve"
- There is an optimal time for investment
- 20 years is a typical system lifetime to amortize investment



N. Holtkamp

SLAC Mission Readiness List (excerpt) with ROI Elements

SLAC

Level Tech Risk	Likely-hood Risk	Overall Risk Exposure	Risk Matrix Level

Before Maint 20 Year Cost	Maint Cost after Replacemt	After Maint 20 Year Cost	Replace Cost

ROI-M %	ROI-M (M$)	ROI-D %

Accelerator Directorate Mission Readiness Improvement List

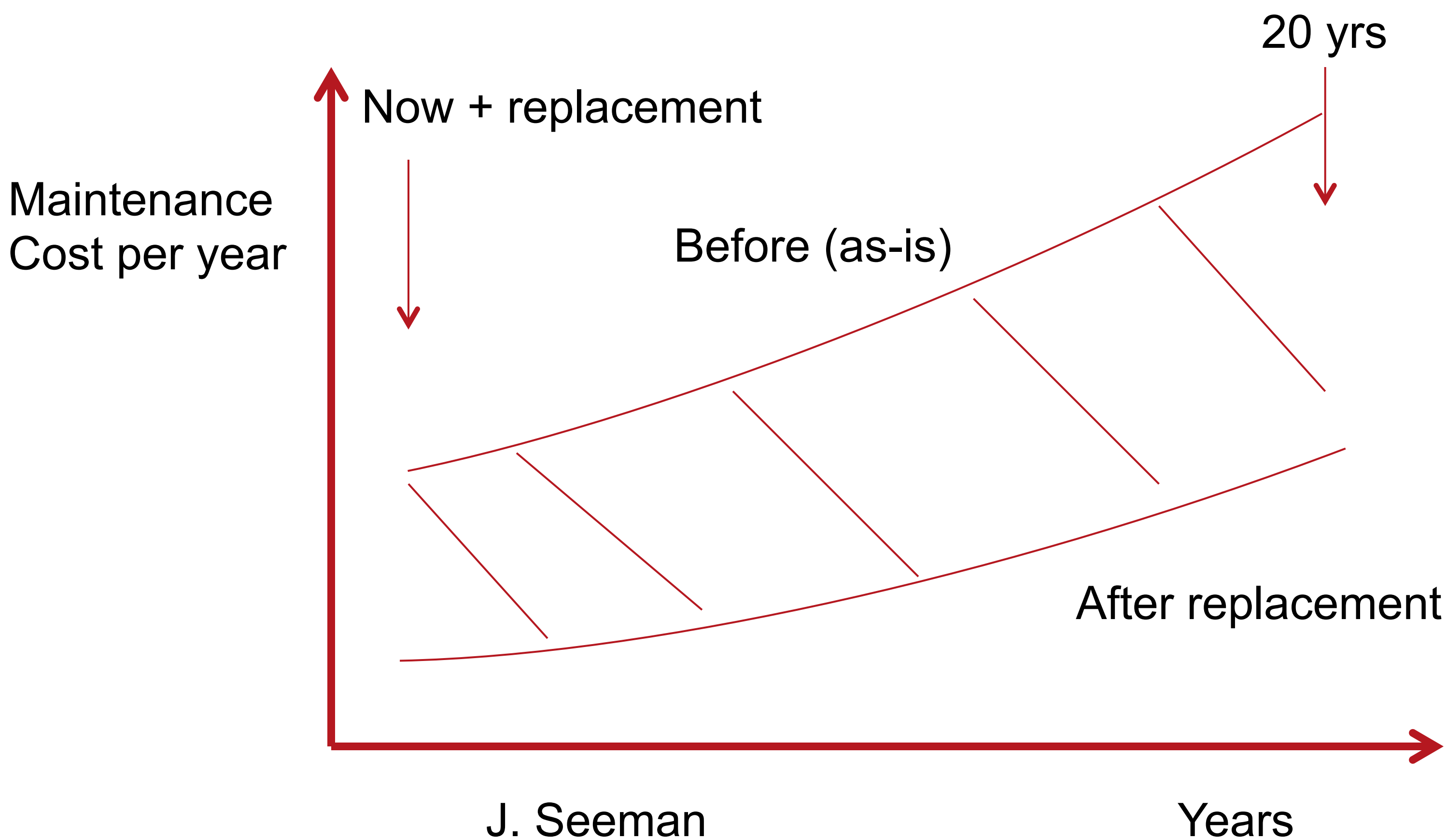
Rev Oct-15-2013

#	MR	Program	Accelerator or Facility	Sub-System	Component at risk	Problem (identified)	Group	Person input	Number units	Schd-Prog Risk	Cost Risk	S&H Risk	Level Tech Risk	Likely-hood Risk	Overall Risk Exposure	Risk Matrix Level	Maint (1yr) Cost before Replacemt (M$/yr)	Maint (10yr) Cost before Replacemt (M$/yr)	Before Maint 20 Year Cost (M$)	Maint Cost after Replacemt (M$/yr)	After Maint 20 Year Cost (M$)	Replace Cost (M$)	20yr ROI-M %	ROI-M (M$)	ROI-D %	ROI-D (M$)	Year for Upgrd	Beam Perf. Impmt
28	MR020	LCLS	Linac BSY	B136 Cable Systems	Cable Trays	To MCC Corroded	CTL	Carrone	1	4	3	2	4	2	8	M	0.100	0.300	6.0	0.0010	0.03	1.35	342%	4.6	211%	2.9	2014	1.0
29	MR019	LCLS	Linac BSY	B136 Cable Systems	Cable Trays	Underbridge Corro	CTL	Carrone	1	4	3	3	4	2	8	M	0.100	0.300	6.0	0.0010	0.03	0.18	3218%	5.8	NA	NA	2014	1.0
30	MR113	LCLS	Linac BSY	PPS	E/O devices, cable plant, access	End of life	CTL	Carrone	1	3	2	1	3	2	6	M	0.200	0.400	8.0	0.1000	2.73	2.18	142%	3.1	-39%	-0.9	2014	1.0
31	MR052	LCLS	Linac BSY	Legacy Elect Sys S21-30/	Legacy Electrical Equipment	EEIP non-complian	MFD	Atkinson	500	1	3	2	3	2	6	M	0.100	0.300	6.0	0.0500	1.36	0.52	792%	4.1	-46%	-0.2	2015	1.0
32	MR058	LCLS	Linac BSY	Vacuum system	B.L. CC Gauge Gate Valve	Obsolete	MFD	Atkinson	22	2	3	1	3	3	9	H	0.100	0.300	6.0	0.0200	0.55	1.07	410%	4.4	386%	4.1	2015	1.0
33	MR059	LCLS	Linac BSY	Vacuum system	B.L. Fast Valve	Obsolete	MFD	Atkinson	5	3	3	1	3	2	6	M	0.010	0.030	0.6	0.0010	0.03	1.04	-45%	-0.5	42%	0.4	2014	1.0
34	MR057	LCLS	Linac BSY	Vacuum system	Pump Stations	Obsolete	MFD	Atkinson	4	3	3	1	3	3	9	M	0.010	0.030	0.6	0.0010	0.03	4.08	-86%	-3.5	263%	10.7	2015	1.0
35	MR155	LCLS	Linac S21-30	Legacy Electrical Sys S2	Legacy Electrical Equipment	EEIP non-complian	AD Mgm	Seeman	3085	1	4	2	4	1	4	L	0.330	0.660	13.2	0.0400	1.09	3.20	278%	8.9	-97%	-3.1	2016	1.0
36	MR023	LCLS	Linac S21-30	Controls Upgrade S21-3	CAMAC	OB+Spares	CTL	Carrone	350	3	3	1	3	3	9	M	0.800	1.600	32.0	0.4000	10.91	6.93	204%	14.2	114%	7.9	2018	1.0
37	MR116	LCLS	Linac S21-30	LLRF S21-30	LLRF, Main Drive Ln, RF coupler	End of life	CTL	Carrone	18	3	3	1	3	2	6	M	0.300	0.600	12.0	0.2000	5.45	5.75	14%	0.8	-74%	-4.3	2019	1.0
38	MR028	LCLS	Linac S21-30	PPS S21-30	Rlys, Interlks, EO, lights	OB,Fail unsafe	CTL	Carrone	5	3	2	1	3	2	6	M	0.200	0.600	12.0	0.1500	4.09	1.93	310%	6.0	-31%	-0.6	2018	1.0
39	MR004	LCLS	Linac S21-30	Tunnel S21-30	Vertical penetrations	Corrosion	FAC	Seeman	177	1	3	2	3	2	6	M	0.040	0.100	2.0	0.0200	0.55	1.53	-5%	-0.1	-82%	-1.3	2017	1.0
40	MR029	LCLS	Linac S21-30	ACS - LCW S21-30	Accelerator Structure	Corrosion	MECH	Seeman	320	3	3	1	3	2	6	M	0.100	0.400	8.0	0.0200	0.55	2.11	253%	5.3	-30%	-0.6	2022	1.0
41	MR074	LCLS	Linac S21-30	Magnet S21-30	Quad Magnets	Unreliable	MFD	Atkinson	85	2	2	1	2	2	4	M	0.060	0.120	2.4	0.0100	0.27	1.50	42%	0.6	-75%	-1.1	2016	1.0
42	MR060	LCLS	Linac S21-30	Vacuum system	Mech Blwr Pmp,Light Pipe	Aging V pump, leal	MFD	Atkinson	1	1	2	1	2	2	4	L	0.020	0.050	1.0	0.0100	0.27	0.69	5%	0.0	-81%	-0.6	2015	1.0
43	MR066	LCLS	Linac S21-30	Vacuum system S21-30	CC Gauge,Manifold,Gate V	Obsolete, Unreliat	MFD	Atkinson	100	3	1	1	3	2	6	M	0.020	0.050	1.0	0.0100	0.27	1.20	-39%	-0.5	8%	0.1	2017	1.0
44	MR099	LCLS	Linac S21-30	Vacuum System S21-30	RGA	Insuff Vac Infor	MFD	Atkinson	10	3	1	1	3	2	6	M	0.035	0.050	1.0	0.0100	0.27	0.43	69%	0.3	200%	0.9	2016	1.0
45	MR069	LCLS	Linac S21-30	Vacuum system S21-30	Sector Fast Valve	Obsolete, Unreliat	MFD	Atkinson	10	3	3	1	3	2	6	M	0.010	0.030	0.6	0.0040	0.11	1.38	-64%	-0.9	7%	0.1	2016	1.0
46	MR063	LCLS	Linac S21-30	Vacuum system S21-30	Sector Ion Pumps-Ultec 500L	Old style, aging	MFD	Atkinson	40	3	3	1	3	2	6	M	0.020	0.050	1.0	0.0050	0.14	1.21	-29%	-0.3	22%	0.3	2017	1.0
47	MR014	LCLS	Linac S21-30	Linac Klystron S21-30	LCLS PFN Cap Replace	End of life	RFARED	Rafael	84	1	3	2	3	3	9	H	0.200	0.500	10.0	0.1000	2.73	5.44	34%	1.8	-49%	-2.6	2016	1.0
48	MR117	LCLS	Linac S21-30	Power Supply	Klystron Solenoid Pwr Sply	Upgrade	RFARED	Rafael	64	2	1	3	3	4	12	H	0.100	0.200	4.0	0.0500	1.36	4.93	-47%	-2.3	569%	28.1	2013	1.0
49	MR122	LCLS	Linac S21-30	Power Supply S21-30	Magnet cables (e.g. S30)	Upgrade	RFARED	Rafael	9	3	1	1	3	2	6	M	0.010	0.020	0.4	0.0010	0.03	1.79	-79%	-1.4	-28%	-0.5	2013	1.0
50	MR085	LCLS	Linac S21-30	RF	Modulator S21-22	Obsolescent	RFARED	Rafael	16	3	2	1	3	3	9	H	0.300	0.600	12.0	0.1000	2.73	2.18	325%	7.1	510%	11.1	2016	1.0
51	MR086	LCLS	Linac S21-30	RF	Modulator S23-24	Obsolescent	RFARED	Rafael	16	3	2	1	3	3	9	H	0.300	0.600	12.0	0.1000	2.73	2.18	325%	7.1	510%	11.1	2015	1.0
52	MR087	LCLS	Linac S21-30	RF	Modulator S25-26	Obsolescent	RFARED	Rafael	16	3	2	1	3	3	9	H	0.300	0.600	12.0	0.1000	2.73	2.18	325%	7.1	510%	11.1	2014	1.0
53	MR151	LCLS	Linac S21-30	RF System S21-30	Mod 6575: Cabinet 2&3 AIP	EEIP non-complian	RFARED	Rafael	80	1	2	1	2	2	4	L	0.100	0.300	6.0	0.0100	0.27	4.85	18%	0.9	-97%	-4.7	2016	1.0
54	MR154	LCLS	Linac S21-30	RF System S21-30	Mod 6575: pulse/bulk cables	Upgrade	RFARED	Rafael	33	1	1	1	1	1	1	L	0.050	0.100	2.0	0.0100	0.27	0.24	610%	1.5	-96%	-0.2	2013	1.0
55	MR148	LCLS	Linac S21-30	RF System S21-30	Mod 6575: T-20s	Replace	RFARED	Rafael	15	2	2	2	2	2	4	M	0.100	0.150	3.0	0.1000	2.73	0.24	13%	0.0	53%	0.1	2013	1.0
56	MR156	LCLS	Linac S21-30	MCOR Power Supplies	Bipolar Power Supplies	Upgrade	RFARED	Rafael	800	2	1	1	2	3	6	M	0.100	0.200	4.0	0.0500	1.36	2.03	30%	0.6	63%	1.3	2013	1.0
109	MR144	SPEAR3	All	Safety Systems	PPS, BCS, BSOICs	Obsolescent	SPEAR3	Schmerge	3	3	2	2	3	2	6	M	0.040	0.060	1.2	0.0100	0.27	2.63	-65%	-1.7	-49%	-1.3	2015	1.3
110	MR105	SPEAR3	SP Booster	Vacuum Booster, Linac	Vacuum chambers	Lack of spares	MFD	Schmerge	30	5	4	1	5	2	10	H	0.025	0.100	2.0	0.0100	0.27	1.43	21%	0.3	1089%	15.6	2014	1.0
111	MR010	SPEAR3	SP Booster	Power Supplies	Bias White Circuit	Serviceability	RFARED	Rafael	1	4	2	1	4	2	8	M	0.010	0.050	1.0	0.0100	0.27	0.64	14%	0.1	533%	3.4	2015	1.0
112	MR009	SPEAR3	SP Booster	Power Supplies	BTS-B2B6 Power Supply	Serviceability	RFARED	Rafael	1	4	2	1	4	2	8	M	0.010	0.030	0.6	0.0100	0.27	0.44	-26%	-0.1	820%	3.6	2016	1.0
113	MR011	SPEAR3	SP Booster	Power Supplies	Pulser White Circuit	Serviceability	RFARED	Rafael	1	4	2	1	4	2	8	M	0.010	0.030	0.6	0.0100	0.27	0.42	-22%	-0.1	864%	3.6	2015	1.0
114	MR104	SPEAR3	SP Booster	Power Supply, Booster,	Bipolar DC PS	Obsolete	RFARED	Rafael	90	2	1	1	2	3	6	L	0.010	0.020	0.4	0.0050	0.14	1.19	-78%	-0.9	177%	2.1	2014	1.0
115	MR102	SPEAR3	SP Booster	RF System	Klystron	End of life	RFARED	Schmerge	1	3	3	1	3	2	6	M	0.100	0.300	6.0	0.0500	1.36	3.92	18%	0.7	-62%	-2.4	2014	2.0
116	MR142	SPEAR3	SP Booster	Electrical Controls	Controls Linac, Booster	Obsolescent	SPEAR3	Schmerge	1	2	1	1	2	2	4	L	0.050	0.100	2.0	0.0250	0.68	2.53	-48%	-1.2	-87%	-2.2	2015	1.0
117	MR106	SPEAR3	SP Linac	Pulsed PS	Chopper	Obsolete	RFARED	Schmerge	1	3	1	2	3	2	6	M	0.020	0.020	0.4	0.0100	0.27	0.98	-87%	-0.9	32%	0.3	2015	2.0
118	MR103	SPEAR3	SP Linac	RF System	Klystron/modulator	Obsolete	RFARED	Schmerge	3	3	2	1	3	2	6	M	0.050	0.100	2.0	0.0250	0.68	1.35	-2%	0.0	-1%	0.0	2016	1.3

MR Return On Investment – Maintenance

"ROI-M" = (MSC-RC)/RC with RC = replacement cost.

MSC=Maintenance Savings Costs integrated over 20 years.



J. Seeman

MR Return On Investment – Down Time (Program Risk)
"We do not get called at 2:00 am to discuss future costs"

SLAC

Use the (probability)(severity) product matrix in evaluating risk impact

- LOW: Minimal Impact with normal oversight needed to ensure risk remains low.
- MODERATE: Some impact. Some special action may be required. Additional management attention may be needed.
- HIGH: Significant impact on safety, cost, schedule, or performance. Significant action required. High priority management attention needed

Probability of Risk Materializing					
Very Likely	Low	Moderate	High	High	High
Likely	Low	Moderate	High	High	High
Unlikely	Low	Low	Moderate	Moderate	High
Very Unlikely	Low	Low	Low	Low	High
	Negligible	Marginal	Significant	Major	Critical

Severity of Consequence

MR Return On Investment – Down Time (Program Risk)

2 risk elements: program schedule (MTTR) and repair costs

Estimate LCLS "cost" for down time, $8k/hr

Down time cost (DT) for an "unlikely" event

- MTTR (significant): (20 years)(1/year)(8 hr)($8k/hr) = $1.28M
- Repair (marginal): (20 years)(1/year)($50k) = $1M
- Total (DT): $2.3M

"ROI-D" = (DT-RC)/RC

- Probability
  - Very unlikely – 0.1/year
  - Unlikely – 1/year
  - Likely – 10/year
  - Very Likely – 100/year

Severity	MTTR	Repair $
Negligible	0.5 hr	$10k
Marginal	2 hr	$50k
Significant	8 hr	$0.2M
Major	25 hr	$1M
Critical	100 hr	$2M

Living with Mission Readiness

"Where is the return on my investment in your system?"

ROI on MR is now a significant KPI

Developing processes and implementing tools to track the relevant data for ROI-M

- Track upgrade project cost to estimate investment (in place)
- Segregate and track the impacted operations costs (TBD)
  - Reactive maintenance (repairs)
  - Preventative maintenance (maintenance)
  - Engineering planning
  - Improvements
  - Replacement

Work Flow Control for Effective Stewardship

Guiding principal: all stewardship activity is engineering-based

- System state and mission requirements are time variant, need engineer engaged in daily O&M
- If you wait until you see the RHS of the bathtub curve, you are “In the hands of God”

System Engineer – single steward for each system

- Addresses all operational demands, 24/7, authorizes all service
- Develops and manages O&M budget
- Provides training and documentation for Techs, qualifies Techs
- Manages system to meet present and future performance needs
- Accountable both to line management and customer

Need to improve gate keeper functions of System Engineer

- Assure all activities are engineering-based
- Further develop budget model; effort-basis, ROI analysis

Conclusions

Performance metrics are required for effective engineering-based stewardship (fatalism is not good engineering practice)

Well formulated performance metrics provide quantitative justification for stewardship efforts

- Controllable characteristic
- Data-based
- Reference value

Use “standardized” data for performance metrics

Cost data tends to be relative rather than absolute

Return On Investment approach normalizes cost data